

Pneumatic Sampler (P-Sampler) for the Martian Moons Exploration (MMX)

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I. Introduction

The Martian Moons eXploration (MMX) mission, led by the Japanese Aerospace Exploration Agency (JAXA), will focus on the exploration of the two Martian moons – Phobos and Deimos (Figure 1). The spacecraft will perform close-up remote sensing and observations of both moons and collect a sample from Phobos for Earth sample return.

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MMX has set the two mission goals: (1) determining the origin of the Martian moons and (2) observing processes in the circumplanetary environment of Mars, based on remote sensing, in-situ observations, and laboratory analyses of returned samples of Phobos regolith [1-2].

To fulfill the mission goals, MMX employs a double sampling approach: Coring and Pneumatic Samplers (Figure 2). The Coring Sampler (C-Sampler), a core soil tube deployed by a robotic arm, providing access to the building blocks of Phobos beneath the surface (>2 cm), and also collect a mixture of near surface material. The P-Sampler, on the other hand, would selectively sample the surface veneer and provides reference of surface component with the C-Sampler.

The double sampling system not only enhances the scientific merits of MMX but also reduces risks associated with the sampling of Phobos. Without enough knowledge of the physical and chemical properties, and the geotechnical conditions of the surface of Phobos (e.g., compositions, temperature gradient/variation, porosity, grain size distribution), having two sampling systems that utilize entirely different sampling approaches is prudent.

II. MMX P-Sampler

The pneumatic (P)-Sampler system will enable MMX to utilize a high-reliability surface sample acquisition system [3]. Using pneumatics to excavate and transport sample, P-Sampler enables MMX to collect sample without physically penetrating the subsurface with any mechanical hardware.

P-Sampler consists of four subsystems: Sampling Head, Control Box, Sample Tube, and Gas Tube (Figure 3).

The Control Box houses several subsystems, including the Pneumatic Subsystem, Sample Canister, Hold Release Mechanism, Momentum Separator and BeamBreaker system for sample verification.

The Pneumatic Subsystem, rated to use 5000 psi of ultra-pure Nitrogen gas to power the P-Sampler, is comprised of a Pressurant Tank, Pressure Transducer, Service Valve, and two Solenoid Valves in series. It designed to be completely reusable (automatically resettable), extremely clean (limited materials and zero lubricants), and very reliable (redundant seals and high reliability actuators).

The Control Box is an “endoskeleton” architecture to ease access and reduce mass. With this architecture, the back plate of the control box becomes the main structural element and all other components are directly bolted to this frame. This saves mass as well as provides access to the high pressure pneumatic system.

The Sampling Head consists of three sets of nozzles: Excavation Nozzles, Transport Nozzles and Retro-thrust Nozzles. Excavation Nozzles are pointed down and are designed to fluidize Phobos material and eject it upwards, into the Sampling Head. Transport Nozzles are designed to push the material up the Sample Tube and into the Sample Canister within the Control Box. Retro-thrust Nozzles are pointed directly opposite of the Excavation Nozzles – these are designed to counter the gas momentum of the Excavation Nozzles and in turn reduce the impulse of the operation – critical in the miniscule gravity well of Phobos.

The Sampling Gas and Sample Return Tubes reside between the Sampling Head and Control box and are responsible for transporting ultra-pure nitrogen gas and fluidized Phobos regolith, respectively. Both Tubes are designed to accommodate the difference in thermal expansion of the aluminum P-Sampler and the composite Lander Leg.

Both tubes connect to the Sampling Head and Control Box. The Sample Transport Tube is fixed relative to the lander leg. On either end, the tube has sliding interfaces with the Control Box and the Sampling Head/Funnel to compensate for thermal expansions differences between the aluminum P-Sampler and composite lander leg. In contrast, the Gas Tube is fixed on both ends since it needs to maintain a pneumatic seal. However, multiple U-bends on both ends give the Gas Tube axial compliance to accommodate changes in length due to thermal expansion / contraction.

III. Testing

Testing is crucial to the development of the P-Sampler. In-situ, the P-Sampler shall sample from a largely undefined surface from a height and angle that is difficult to predict. Such circumstances therefore preclude the use of analysis when developing the functional parameters of the instrument. To address this, the P-Sampler development program has defined a process that relies on extensive testing. This process can be described as follows: 1) Define – research and define baseline sampling conditions, 2) Test – Utilize pneumatic prototype hardware to test in baselined conditions, 3) Analyze – Observe and record data to analyze the effectiveness of the pneumatic sampler, and 4) Design – Strategically update design to improve sampling performance and define limitations for the MMX application of pneumatic sampling.

To date, over 200 sampling tests of the pneumatic sampling technology have been performed for the MMX application.

Several different simulants have been used in the test process including beach sand, crushed Aircrete, 3M Glass Bubbles, and two Phobos simulants developed by University of Central Florida: PCA-1 and PGI-1. PCA-1 is based on Phobos Captured Asteroid theory while PGI is focused on Phobos Giant Impact theory [4].

The following are key findings of the P-Sampler testing: 1) successfully met the sample collection and impulse requirements at sampling heights of 10 cm, 2) successfully collected sample in various simulants, and 3) sensitivity studies show that P-Sampler is tolerant to position and orientation variability from landing, within the requirements set upon by the MMX spacecraft.

IV. Acknowledgments

The project is managed by the Planetary Missions Program Office at NASA's MSFC for the agency's Planetary Science Division. We would like to thank Dan Britt and Anna Metke of University of Central Florida for providing two Phobos simulants: PGI-1 and PCA-1.

V. Optional Supporting Materials

A. Figures

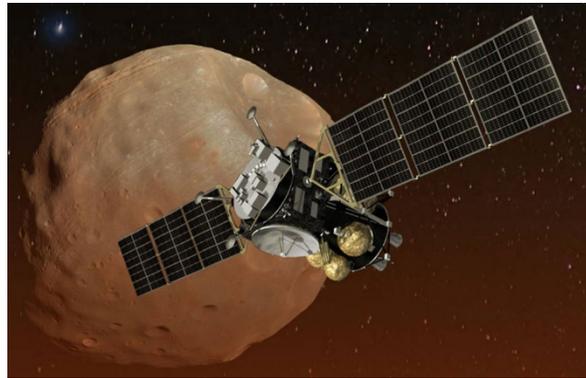


Fig 1. The Martian Moons eXploration (MMX) mission, developed by the Japanese Aerospace Exploration Agency (JAXA).

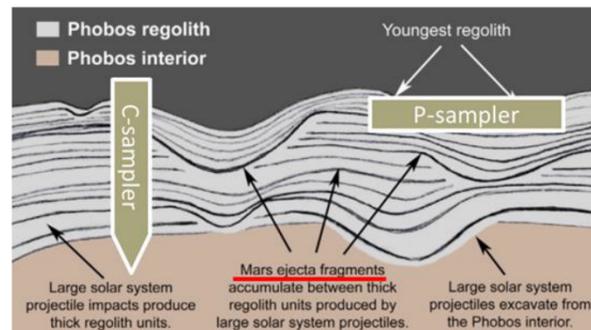


Fig 2. C-Sampler and P-Sampler will address MMX goals #1 and #2, respectively. The Phobos stratigraphy is after Ramsley and Head 2013 [1].

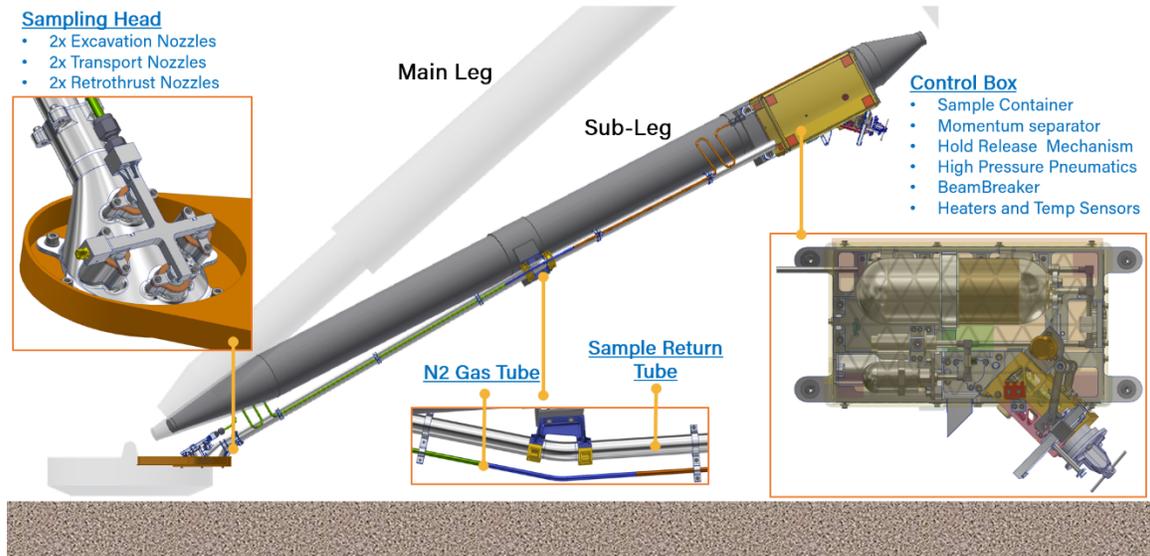


Fig 3. Components of P-Sampler.

B. References

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